makes the operation with the clamp, notwithstanding the numerous and very large vessels, almost entirely bloodless.

The removal of the penis and testicles can in all probability be always avoided by Turner's operation, and should at least be always attempted, although Esdaile regards it as dangerous not to remove these organs in tumors which weigh more than fifty pounds. In two cases reported by Lloyd, tumors of sixty-five and sixty-one pounds in weight, respectively, were successfully removed with preservation of the penis and testicles. In these operations soft twisted ropes were used as constrictors and the flaps made according to the method of Turner.

The preservation of the penis and testicles is the more important because the genital functions remain undisturbed in the case of patients suffering from elephantiasis.

RESPONSES TO THE ALTERNATING GALVANIC CURRENT IN NORMAL AND DEGENERATE MUSCLES.

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I.

By Dr. Starr.

The following article presents in a concise form the results of a scientific investigation upon the effects of an alternating galvanic current of electricity upon normal and degenerate muscles. The research has been made by one who is thoroughly conversant with all recent advances in the knowledge of electricity and of all its mechanical appliances, and who has had exceptional facilities at Princeton for the prosecution of careful experiments by the aid of the best apparatus. Mr. Young is a practical electrician, who has been for three years recovering from a condition of acute anterior poliomyelitis of considerable extent, produced by the passage of an alternating current through his entire spinal cord. His treatment has been partly mechanical, various devices for exercising paralyzed muscles having been made and used by him with success; partly electrical, the muscles being daily stimulated by alternating currents of moderate strength in the manner described by him; partly medicinal, by arsenic and strychnine, with results whose effects have been objectively proven by electrical tests in the manner presented in this paper. The results reached appear to be of importance in confirming Neumann's statements regarding the physiology of muscular response to electrical stimulation; in presenting a series of facts regarding the effect of the application of alternating currents to muscles, not as yet investigated; in determining the possibility of reaching prognostic facts of great value in doubtful cases by electrical tests with the alternating current; and, finally, in demonstrating the effect of strychnine and arsenic on the nervous functions.

Erb says (Ziemssen's *Cyclopædia*, Amer. edit., vol. xi. p. 433), "the extraordinary fact that in the reaction of degeneration the muscle fails for a long time to react to the stimulus of the faradic current while it readily responds to the galvanic stimulus has been explained by Neumann in the following satisfactory manner: 'Muscles,' he says, 'that have undergone this pathological change have simply lost the power of responding to currents of momentarily short duration, while they react in an increased and qualitatively altered manner to currents of longer duration. But inasmuch as faradic currents are, without exception, currents of only momentary duration, the muscles do not react to them. . . . The value of the change by which the muscular tissue loses its normal power of reacting to currents of short duration is a question the solution of which must be left to physiologists.'"

Mr. Young has shown that the length of duration of stimulus required to cause contraction in a paralyzed muscle varies in accordance with the degree of progress toward recovery; varies also in accordance with the subjective feeling of strength; varies also in dependence upon the use of strychnine in interrupted or continuous dosage.

The practical result of his investigation is to enable a physician by careful measurement to construct a prognostic curve which will enable him to give certain hope of recovery to a patient completely paralyzed, or will establish the unfortunate fact of a permanent loss of power. It also makes it evident that in using arsenic or strychnine as a stimulus to the spinal cord it is better to give the drug for short periods with intermissions than continuously.

The accuracy and care of the investigation and the importance of the conclusions arrived at should attract the attention of physiologists, and especially of neurologists, to this contribution to medical science.

II.

By Mr. Young.

Certain nervous diseases are followed by a loss of voluntary contraction in the muscles, and in such muscles we sometimes notice electrical reactions which present a marked contrast to those of muscles in their normal condition.

A normally healthy muscle responds to the rapidly interrupted current from the faradic coils, and the muscle remains permanently contracted as long as the current is applied.

On applying the perfectly steady current of a galvanic battery we find the following effects: With the negative electrode on the muscle, and the positive anywhere on the body remote from the muscle, we get a contraction at the moment the circuit is completed; but this contraction, unlike that produced by faradism, is not tetanic. If we now interchange the electrodes we find that the muscle responds also to the positive pole of the battery, but not so strongly as to the negative. We again notice that, during the interval between making and breaking the circuit, the muscle tends to return to a state of rest.

On applying the above tests to a degenerated muscle we find, first, no response whatever to the faradic current. In the second place we find the responses to a galvanic current appearing in reverse order; viz., while a healthy muscle responds more vigorously to the negative than to the positive electrode, on completing the circuit, the degenerated muscle responds more vigorously to the positive; and these reactions, in the case of a degenerated muscle, are again reversed on breaking the circuit.

If we now examine a muscle which is regaining its power after being paralyzed, we may find the response to the positive pole of a galvanic battery the stronger; the responses to positive and negative may be equal; or that to the negative may be the stronger, as in the case of a normally healthy muscle. On applying the faradic current we may find no response, a response to but one of the electrodes, or a response to both, according to the condition of the muscle and the strength of the current applied.

It is well known that the faradic coil does not give a true alternating current. The current is strong in one direction and weak in the other, so that one electrode is a strong positive and weak negative, while the other is a strong negative and weak positive.

The writer, who has been able to supply the muscles for testing in his own person, has at different times found all the responses referred to above. Where a muscle has responded to but one electrode of the faradic coil it has invariably been to the strongly positive; but in such a case it has sometimes been possible to obtain a response to the strongly negative by increasing the strength of the current. As might be supposed, that muscle has shown a stronger response to the positive pole of a galvanic battery than to the negative.

Dr. Starr, in his article on "Therapeutic Uses of Electricity,"[1] says: "The difference of response to the faradic current from that of voltaic alternatives, in conditions known as the reaction of degeneration, is not to be ascribed to any difference in the nature of the current, but only to the fact that the degenerated muscle will not respond to changes of state so rapidly produced."

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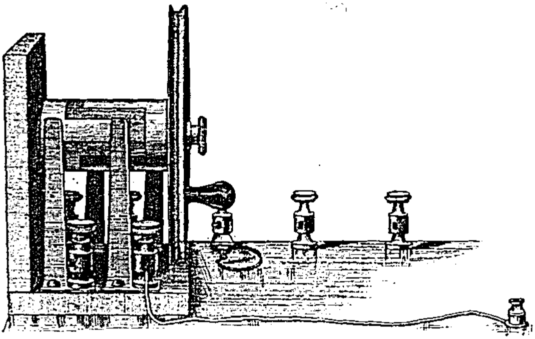
[1] The Medical News, March 30, 1889.

There must be a certain amount of lag in the response of any muscle to an applied electro-motive force, though in the case of a healthy muscle it must be very small, and probably would have to be measured in thousandths of a second, if not in some smaller unit. But in a degenerated muscle it would appear that this lag amounts to something appreciable. If, by means of a suitable commutating device, we apply voltaic alternatives to such a muscle, and have some means of measuring the rate of alternation at which the muscle ceases to respond to a given current, we can ascertain the lag of that muscle's response behind the applied electro-motive force.

It has occurred to the writer that this test might possibly give some knowledge of the condition of a degenerated muscle, and with this end in view the following apparatus was assembled:

First, a rotary commutator (Figs. 1 and 2) to give voltaic alternatives. For every revolution of this commutator the current is reversed six times. The pulley wheel of the commutator is four inches in diameter and is driven from a half-inch pulley on a small electric motor (Fig. 3) Current is supplied to the motor from a storage battery; and by means of a variable resistance the motor can be made to run at any speed from about 500 to over 6000 revolutions per minute.

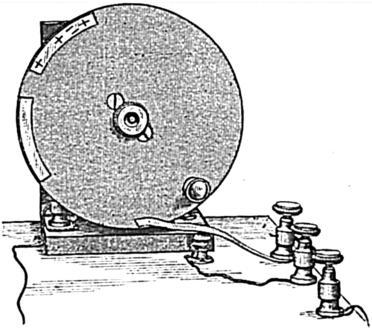
FIG. 1.



Commutator.

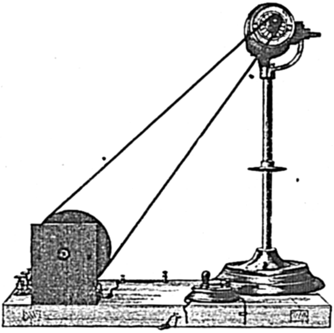
The speed of the commutator is recorded automatically on a chronograph, which may be thrown in and out of circuit at pleasure by a switch placed within easy reach (see Fig. 3, near the base of the motor).

Fig. 2.



Commutator, with arrangement for completing chronograph circuit at every revolution of wheel.

Fig. 3.



Commutator and motor.

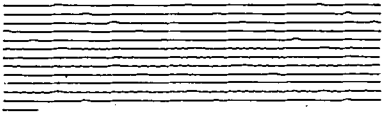
The chronograph (which is near at hand in the astronomical observatory of Princeton) records every other second from a standard clock.

The recording of the commutator revolutions is effected in the following manner:

On referring to Fig. 2 there will be seen, at the base of the commutator, a projecting tongue of brass, so placed that at every revolution a little knob on the commutator wheel strikes it and depresses it, causing it to come in contact with the head of a screw placed beneath. This, when the switch (referred to above in Fig. 3) is closed, completes the chronograph circuit, so that each revolution of the commutator wheel is recorded.

Fig. 4 shows the appearance of a record made by the chronograph. The first five lines show the clock record alone. In the lines below each little tooth stands for one revolution of the commutator. Now, as there are six reversals of the current for every revolution of the commutator, it is a simple thing to compute the number of reversals per second from the chronograph record.

Fig. 4.



Fragment of chronograph sheet showing clock record, together with records made by commutator when run at different speeds.

The current which we apply to the muscle in our test is supplied by a battery of Leclanchè cells giving about 40 volts, is regulated by a liquid resistance which we can vary at pleasure from about 30,000 ohms to less than 1 ohm, and is measured by a milliampère-meter. In connection with the milliampère-meter is a switch to cut it out of circuit when the commutator is turning. It may be well to mention the fact that the resistance of the milliampère-meter is so small compared with the total resistance of the circuit that our cutting it out changes the value of the current by only an inappreciable amount.

In the following tests the electrode placed on the muscle we wished to examine was circular in shape and about three-fourths of an inch in diameter.

Test on biceps of right arm. This muscle has lost all power of voluntary contraction. In it we find the usual phenomena which accompany degeneration, viz., no response to faradism, and with the galvanic current a stronger response to the positive than to the negative pole. We apply the small electrode to the muscle at the motor point, the other electrode, a sponge, being placed on the left arm near the shoulder. On adjusting the variable resistance to give a current of about ten milliampères through the muscle, and setting the commutator in motion, we find the effect of the voltaic alternatives is as follows:

(*a*) We start at a low rate of speed and find the muscle responds separately to each reversal of the current.

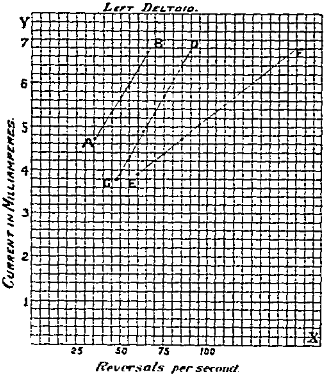
(*b*) At a higher rate of speed the muscle becomes permanently contracted and begins to lift the forearm, and the arm is held up as we increase the speed up to a certain point.

(*c*) We still increase the speed, little by little, and we now observe the muscle gradually relax; the arm sinks down; and at last we attain such a speed that, on breaking and making the circuit by means of a suitable key, we find the muscle refuses to make the slightest response to the current alternating at such a rate.

To show that the sinking down of the arm, observed at *c*, was not due to fatigue of the muscle, we have the circuit closed and gradually reduce the speed of the commutator. The muscle begins to contract as the rate of alternation grows less; the forearm is again lifted and held up for a while; the muscle begins to relax, and the arm gradually sinks down again; and, at the end, the muscle contracts separately for each reversal of the current. In short, the phenomena *a*, *b* and *c* appear again, but in reverse order.

On making the above test with currents of different strength, we find that the rate of alternation at which the muscle ceases to respond varies with the strength of the current used. This being so, by making three or more tests on a muscle for disappearance of contraction, with dif-

FIG. 5.



A B, from test made October 22d.
C D, " " December 25th.
E F, " " February 25th.

ferent strengths of current, we can plot the whole result on cross-section paper, and draw a line which may, perhaps, tell us something about the condition of the muscle at the time the test was made. Fig. 5 shows three such lines drawn from tests made respectively October 22d, December 25, 1890, and February 25, 1891, on the left deltoid. The condition of that muscle was practically the same as that of the biceps of right arm. As will be seen, the current, in milliampères, is plotted on the axis of Y, and the rate of alternation (reversals of current per second) on the axis of X. The lines A B, C D, and E F, represent respectively the October 22d, December 25th, and February 25th tests, and demonstrate an increasing power of response in this muscle to the alternating current.

Let us, for brevity, call the rate of alternation at which the muscle ceases to respond to a given current, the *critical rate* for that current. On referring to Fig. 5 it will be seen that, in the line A B, the critical rate for a current of 5 milliampères is about 41; in C D, for the same current, it is about 64; and in E F about 93. Of course the critical rates for any other current can also be compared by a glance at the three lines given in the figure.

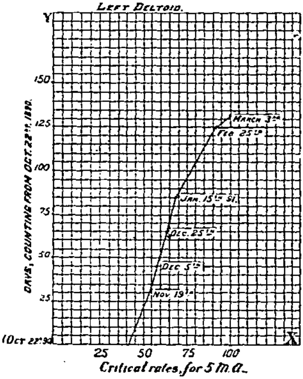
In a series of tests made on the right and left deltoids, and covering a period of about five months, the changes in the critical rates have been anything but uniform, and the two muscles have not always varied alike. But the writer has noticed that on days when he felt energetic and "full of snap," so to speak, the critical rates were generally higher than those of the preceding tests; and on days when there was a feeling of lassitude the critical rates were generally no higher than those of previous tests, and they were often lower.

Now, to combine a series of tests in a single line, suppose, for example, we measure off time, in days, on the axis of Y, and the critical rates for some given current on the axis of X. The line we get may be called a graphic representation of changes in the condition of the muscle tested, with respect to electrical reaction, during the interval between the first and last test. If the line incline to the right there has been a gain; if it be vertical, no gain; and if it incline to the left it indicates a loss. In Fig. 6 we have drawn such a line from tests made on the left deltoid. The line demonstrates the progress toward recovery in that muscle.

After the experience gained in following up a large number of muscles by the critical rate test, it seems evident that it might be possible to draw what could be called, in general, a prognostic line of a given muscle, after a certain number of tests had been made on that muscle at stated intervals.

While the tests given here are merely tentative, and have been made without any former experience to guide us, they seem to make it obvious that, given a degenerated muscle which will not respond to faradism, but will respond to a current alternating at a much slower rate, we can ascertain the rate of alternation at which the muscle first ceases to respond to a given current, by beginning at a slow rate and gradually increasing. It is also clear that this rate varies with the strength of current applied, being higher for a stronger current and lower for a weaker; and the fact that the different points in each test in Fig. 5 lie so nearly in the same straight line makes it look as if this rate varied *directly* with the strength of current, at least within the limits of these tests.

FIG. 6.



Prognostic line.

We, moreover, think we are justified in assuming that if, with a given current, a healthy muscle will respond to a rate of alternation which will not affect a degenerated one, an increase in the rate to which the degenerated muscle will respond shows increased susceptibility in that muscle, and a tendency to approach, in some way, the condition of a healthy one.

We have noticed incidentally a coincidence between a change in the electrical response and the use of medicine (acid. arsen. $\frac{1}{30}$, strych. $\frac{1}{50}$, t. i. d.). It has seemed that we got a better response of the muscles from about the third day after beginning the medicine and that this improvement continued about a week; after which time the response seemed to be less vigorous. This can be seen by a study of the following table. This also shows that the cessation of the medicine after it had been taken for a month continuously was followed by an increase in the response. It seemed, therefore, that better results were secured by taking the medicine for ten days and intermitting for ten days than by taking it continuously.

Responses of the Left Deltoid Muscle.

	Critical rates.		
	With 3.8 milliampères.	With 4.7 milliampères	
October 22,	22	36	No medicine.
November 13,	38	48	Medicine from November 5th to December 3d.
" 19,	47	53	
December 5,	36	53	Medicine stopped.
" 10,	45	58	
" 17,	38	52	
" 25,	48	62	
January 2,	53	62	
" 8,	33	47	Medicine from January 6th to February 2d.
" 15,	60	76	
" 26,	47	51	
February 2,	57	78	
" 9,	53	69	Medicine stopped.
" 19,	62	95	
" 23,	53	80	
" 25,	54	84	Medicine from February 24th to March 10th.
March 3,	63	95	
" 10,	52	83	Medicine stopped.
" 16,	60	87	
" 18,	54	77	

The writer, making no claim to medical knowledge, feels some diffidence in approaching the medical profession with an article upon a subject which lies within their peculiar province. But having good reason to be interested in the subject of degenerated muscles, and being also more or less familiar with the handling of electrical apparatus, and having the chronograph and most of the other appliances at hand, he undertook to test his own muscles by this method. The results obtained seemed so interesting that, at the suggestion of Dr. Starr, the method is here given.